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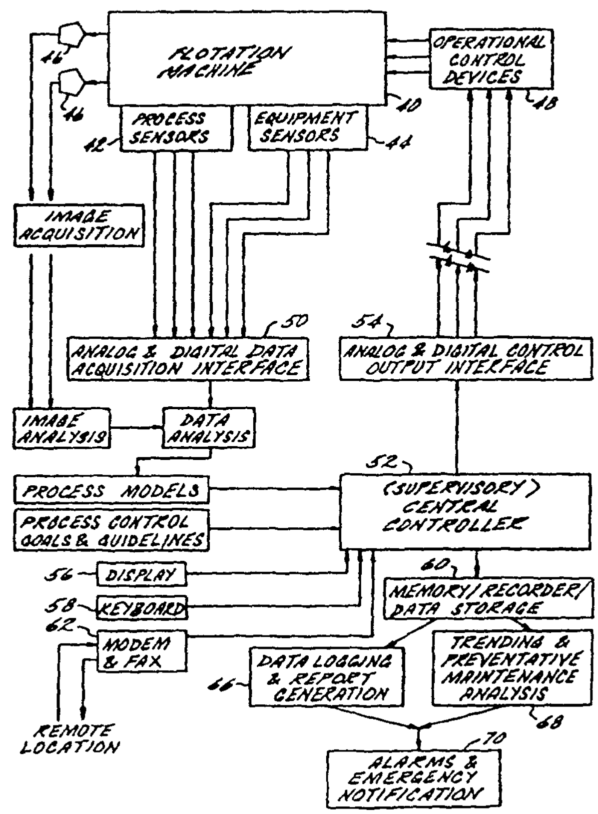
(54) Title: METHOD AND APPARATUS FOR CONTROLLING FROTH FLOTATION MACHINES

(57) Abstract

Computerized, "intelligent" system (110) and methods for monitoring, diagnosing, operating, and controlling various parameters and processes of flotation machines (40) are presented. The computer control system actuates at least one of a plurality of control devices (48) based on input from one or more monitoring sensors (42, 44) so as to provide real-time, continuous, operational control. The response of the control system is based on the system's own process model which in turn is based on sensor input and one or more advanced analysis techniques including but not limited to neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, and combinations thereof. Process and operating parameters of particular interest include rate and amount of chemical reagent addition, froth thickness, power consumption and aeration rate. In a particularly preferred embodiment, the apparatus comprises a froth flotation machine with at least one video sensor (46) providing input which is analyzed by a process model generated by a combination of statistical methods and neural networks. As a result of the analysis, at least one output may be generated to activate a control device (48) that effects changes in operating variables as suggested by the process model. In another particularly preferred embodiment, the apparatus comprises a froth flotation machine with at least one laser spectrometer (114) providing input with respect to elemental composition of the input (feed) and of the output (effluent) streams.



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METHOD AND APPARATUS FOR CONTROLLING FROTH FLOTATION MACHINES

Background of the Invention:

1. Field of the Invention

This invention relates generally to froth flotation machines for the separation of particles from a liquid slurry or pulp. More particularly, this invention relates to methods and apparatus for automatically monitoring, operating, and controlling continuous feed flotation machines using "intelligent" computer control systems and remote sensing devices, particularly laser spectroscopy type sensing devices.

2. Brief Description of the Prior Art

Flotation machines are used in many industrial applications for separation of particulate materials from suspensions in a liquid, usually water. The particles to be removed from the suspension are treated with reagents to render them hydrophobic or water repellant, and a gas, usually air, is admitted to the suspension in the form of small bubbles. The hydrophobic particles come into contact with the bubbles and adhere to them, rising with them to the surface of the liquid to form a froth. The froth containing the floated particles is then removed as the concentrate or product, while any hydrophilic particles are left behind in the liquid phase and pass out as the tailings. Flotation machines find particular utility in the metals recovery industry, providing superior recovery of metals or metallic minerals from a solid/liquid mixture known as a "pulp," "slurry," or "gangue." The flotation process can also be applied to the removal of oil droplets or emulsified oil particles, as well as to fibrous or vegetable matter such as paper fibers, bacterial cells, and the like.

In most applications, reagents known as collectors selectively render one or more of the species of suspended particles hydrophobic, thereby assisting the process of collision with and collection by the air bubbles. It is also usual to add frothing agents to assist in the formation of a stable froth on the surface of the liquid. The process of adding various reagents to the system is known as conditioning.

Flotation machines have been developed in a number of different, known configurations. In some conventional embodiments, the flotation machine includes a

receptacle, a cell or tank with substantially vertical walls, and an inner rotating member known as a rotor-disperser. The rotor provides agitation to maintain suspension of the pulps, and may also draw external air into the tank through a standpipe. The disperser breaks the air into minute bubbles and disperses it uniformly through the pulp, while also providing mechanical mixing of the air and pulp. Such cells may also include a false bottom and a draft tube to provide a channelized flow path, ensuring maximum slurry recirculation and air/slurry mixing. In other conventional embodiments, the rotor functions only for agitation, and aeration is provided by an external means, usually a blower or compressor. Alternatively, air may be dissolved into a liquid, which is then injected into the pulp or slurry. The air used may be atmospheric air, or an inert gas such as nitrogen or argon. Other proposed flotation cells include a tank and a means for generating ultrasound, which acts to agitate the pulp and thereby achieve solids separation, as is described in U.S. Patent No. 5,059,309 to Jordan. Alternatively, separation of particles may be achieved by a combination of air, and magnetic and/or electrical fields as described in U.S. Patent No. 5,224,604 to Duczmal and Schneider.

Another known configuration of a flotation machine is the column. In a column, the conditioned suspension is introduced toward the top of the receptacle, a tall vertical column, and air bubbles are formed in the bottom of the column by blowing pressurized air through a diffuser. A layer of froth bearing the floatable particles forms above the liquid and overflows from the top of the column. The position of the froth-liquid interface is maintained at a desired level by controlling, for example, the flow of liquid from the bottom of the column. Optionally, wash water is introduced near the top of the froth layer to create a downflow of liquid which tends to reduce the entrainment of undesired gangue particles in the froth overflow. In these types of flotation columns, the liquid flows downward while the bubbles rise vertically upward. Since the rise of bubbles is related strongly to their size, the bubbles must be above a certain critical diameter to rise through the liquid and into the froth layer. Various other alternative embodiments of the column flotation machine have been described, for example in U.S. Patent No. 4,938,865 to Jameson, which introduces an air/slurry mixture into the column where separation takes place.

Efficient and effective operation of flotation machines requires monitoring and controlling a multitude of process and operational parameters. By "process parameters" is meant such parameters as slurry levels and bubble size, as described above. Other process parameters include but are not limited to the density of the pulp in the chamber of the flotation machine, bubble concentration and distribution, product and tailings removal rates, reagent addition and consumption rates, air flow, solids concentration, froth mass and volume, froth level, pulp level, feed rate, and the like. "Operational parameters" is meant to include various flotation machine operating parameters such as rotor speed and position, draft tube position, crowder position, power consumption, and the like. These classifications and examples are for convenience and example only.

Flotation machines present challenging problems with respect to the design and installation of sensors associated with the flotation machines, the acquisition of various measurements, the ability to communicate data and power into and out of the flotation machine, as well as the ability to provide control devices within the machine and actuate those control devices in response to a command from a central control computer. A special challenge has been to improve efficient control of the various above-discussed parameters. Each of these parameters must be adjusted to optimize both the economic operation of the plant, as well the operating conditions, i.e., efficient throughput and desired levels of purification.

Flotation machines are normally controlled by simple, feedback or feed forward control loops. Various devices have been described which may be used to monitor important parameters in flotation machine operation. The most common of these describe a flotation machine separation control system comprising a controller (e.g., a microprocessor) which communicates with one or more sensors and in response to information received from the sensors, actuates a control apparatus (e.g., a valve) to adjust one or more control parameters. For example, a control system addressing the level of pulp is described in U.S. Patent No. 4,343,654 to Lambert, wherein a computer communicates with a level sensor, and based on these signals and preprogrammed instructions from the computer's memory, sends control signals to a venting element which regulates air venting and thereby adjusts the degree of frothing.

U.S. Patent No. 5,011,595 to Meenan uses feed forward and feedback control methods to detect solids concentrations and adjust the rate of chemical addition to feed streams. The control system includes optoelectric detectors responsive to different solids concentrations and slurry parameters. The detectors forward signals regarding the solids concentrations and slurry parameters to a process controller. In response, the process controller adjusts the rate of addition of chemicals to the feed stream of the froth machine to control the separation of solids from impurities. The controller calculates a feed forward output from the signals and the controller output adjusts the addition of different chemicals or additives to the processing machine. The controller also calculates a feedback output after receiving a signal from a third detector which monitors the extent of separation and recovery of solids from the processing machine. Related patents include U.S. Patent No. 4,797,550 to Nelson and Oblad and U.S. Patent No.4,797,559 to Oblad, et al., which disclose a method and apparatus for determining the reflectivity of the tailings from a coal flotation machine using a laser and bifurcated fiber optic cell to deliver signals. Another control system directed to controlling the quantity of froth is disclosed in U.S. Patent No. 5,062,964 to Ortner and Pfalzer. A probe measures the level or amount of foam, and transmits a signal to a controller or regulating apparatus, which in turn controls the amount of air introduced into the system by way of a valve. Control of multiple parameters is achieved in U.S. Patent No. 3,551897 to Cooper, which describes measurement of various operating conditions, then calculation of a plurality of coefficients that together with certain equations describe the process at a particular point in time, and then utilization of the same equations to adjust certain parameters in order to optimize operating conditions and maximize profitability.

For the most part, the control systems of the prior art address only one or two process or operational parameters, for example controlling the level of liquid or froth. In U.S. Patent No. 5,073,253 to Bishop and Gray, a float supported by the froth works in tandem with an ultrasonic level detector to provide a measurement of froth level. U.S. Patent No. 4,938,865 to Jameson utilizes a controller to operate a valve that introduces air into the top of a column. US. Patent No. 4,552,651 to Sandbrook and Scandrol discloses devices to measure pulp density and pulp level. The two signals are then combined to a single signal which is utilized to control liquid level in the machine by adjusting the rate of withdrawal of

tailings. U.S. Patent No. 5,192,423 to Duczmal and Schneider use a control device to maintain the desired liquid level and to optimize the collection of froth.

Other simple controllers have been used to measure and adjust the density of feed or pulp. For example, U.S. Patent No. 5,368,166 to Chumak, et al. discloses a control device to measure the level and density of pulp and to control the flow rate of water and frothing agent. A differential densitometer for continuously measuring total undissolved solids in a liquid in U.S. Patient No. 5,417,102 to Prevost.

The rate of addition of chemical reagents for conditioning is one of the more important process parameters to control. This rate affects both the quality of the product (i.e., the amount of mineral extracted and the purity), as well as the cost of the overall process. There have been a number of disclosures addressing this parameter, in addition to U.S. Patent No. 5,011,595 discussed above. U.S. Patent No. 4,810,371 to Fonesca discloses a system to control the coal content of coal tailings, including detecting the coal content of the tailings from the flotation cell and controlling the supply of additives to the machine to optimize slurry coal recovery. A method and apparatus for sensing variations in solids content in at least one output stream and then adjusting the amount of flotation reagent is described in U.S. Patent No. 4,731,176 to Macdonald. A particle size analyzer is used in U.S. Patent No. 4,559,134 to compare a size analysis of solid particles in a separated stream with a size analysis of solid particles in a feed stream. The rate of addition of collector reagent is adjusted in response by a controller.

An important operating parameter is the power consumption of the flotation machine. Maximizing efficiency of the machine by proper rotor, disperser, and draft tube placement could represent significant savings in the cost of operation. However, it is not believed that any of the prior art has addressed a control system specifically designed to minimize power consumption while maximizing efficiency and purity of product.

Furthermore, it is not believed that any of the aforementioned prior art provides a comprehensive, computerized, "intelligent" control system for operating, controlling, and monitoring various flotation machines. The ability to provide precise, real time control and monitoring of such flotation machines constitutes an on-going, critical industrial need.

Summary of the Invention:

The above-discussed and other problems and deficiencies of the prior art are overcome or alleviated by the several methods and apparatus of the present invention for providing computerized, "intelligent" systems for operating, controlling, monitoring and diagnosing various parameters and processes of flotation machines. By "intelligent" is meant use of computerized, control methods including but not limited to neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, or a combination thereof. Thus in preferred embodiments (but not necessarily all embodiments), this invention comprises at least one of these control methods and other methods more advanced than conventional, stabilizing control. An intelligent flotation machine of the type herein disclosed has the capability of sensing information about itself, predicting its own future state, adapting and changing over time as process and operational conditions change, knowing about its own performance, and changing its mode of operation to improve performance. Specifically, the control system of the present invention regularly receives instrument readings, digitized video images, or other data indicating the state of the flotation machine; analyzes these readings in terms of one or more self-generated, continuously updated, internal models; and makes changes in operating variables as suggested by the internal models.

In accordance with the present invention, a computer control system actuates at least one of a plurality of control devices based in part on input from one or more monitoring sensors so as to provide real time continuous operational control.

It will be appreciated that it is difficult to sense and communicate certain parameters in real time within flotation machines. Thus, in accordance with an important feature of the present invention, a variety of technologies including ultrasonic absorption and reflection, laser-heated cavity spectroscopy, laser-induced breakdown spectroscopy (LIBS), laser-induced mass spectroscopy (LIMS), X-ray fluorescence, neutron activation spectroscopy, pressure measurement, microwave or millimeter wave radar reflectance or absorption, and other optical and acoustic methods may be utilized.

In a preferred embodiment, the sensor or sensors comprise a means for determining input stream composition and particle size. Ideally, such a sensor would provide the data

regarding the input stream without the necessity of removing samples from the process flow in order to be analyzed at a separate location. Thus, a preferred sensor includes sensors utilizing laser spectroscopy (e.g., laser-induced breakdown and laser-induced mass spectroscopy). Such sensors may oscillate in an arcwise path, or move linearly along the process flow or radius of the tank to provide a profile of the process stream without the necessity of removing individuals samples from the process stream. Alternatively, multiple, spaced sensors may be used to obtain a complete process stream profile.

A particularly preferred embodiment of the present invention employs an imaging system comprising video cameras producing images which are converted to data usable by the process models of the present invention. This embodiment will further comprise an advanced control system employing both pattern analysis by neural networks, as well as statistics and color vector analysis. Mapping of high-dimensional input vectors to lower-dimensional maps in a topological order-preserving manner by these advanced control systems can be used to track to performance of a flotation process on a continuous basis, which is highly advantageous when monitoring banks of flotation cells.

The computer controller used in the system of the present invention is preferably a personal computer or workstation, with a associated display device (CRT screen) and input/output device (keyboard or touch-sensitive screen). The controller may be located at the froth flotation machine or at a remote location such as a central control room in a plant. Importantly, the controller may control one or a plurality of flotation machines at a single or plurality of sites.

The above-described computerized control and monitoring system for froth flotation equipment provides a comprehensive scheme for monitoring and controlling a variety of input and output parameters as well as a plurality of operational parameters resulting in greater efficiency, optimization of operation, and increased safety.

The above-discussed and other features and advantages of the present invention will be appreciated and understood by those skilled in the art from the following detailed description and drawings.

Brief Description of the Drawings:

Referring now to the drawings wherein like elements are numbered alike in the several FIGURES:

FIGURES 1A - D are schematic sectional views of flotation cells and flotation columns with which the monitoring and control system of the present invention is used;

FIGURE 2 is a schematic view of the monitoring and control system for a flotation machine in accordance with the present invention;

FIGURE 3 is a schematic view of a preferred monitoring and control system employing a LIBS or LIMS sensor system in accordance with the present invention;

FIGURE 4 is a schematic view of a monitoring and control system employing a LIBS or LIMS sensor for monitoring the composition and particle size of a dry or dewatered process flow according to the present invention;

FIGURE 5 is a schematic view of a monitoring and control system employing a LIBS or LIMS sensor for monitoring the composition and particle size of a dry or dewatered process flow according to the present invention; and

FIGURES 6A-B are schematic views of a monitoring and control system employing a LIBS or LIMS sensor for monitoring a wet or moist process stream in accordance with the present invention.

Description of the Preferred Embodiment:

This invention relates to methods and apparatus for automatically controlling, operating, and monitoring flotation machines using "intelligent" computer controlled systems and remote sensing devices. By "intelligent" is meant the use of computerized control methods including but not limited to neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, or a combination thereof to analyze input in terms of one or more self-generated, continuously updated, internal models, and to make changes in operating variables as suggested by the models. It is to be understood that the term flotation machine is used in its most general sense, being inclusive of traditional flotation cells, or flotation columns, wherein flotation may be accomplished by a variety of means, including air, ultrasound, magnetic or electrical

fields, or a combination thereof. It is further to be understood that flotation machine in the context of the present invention may refer to a single cell or column, or to a bank of cells or columns.

Referring to FIGURES 1A-D, simplified examples of flotation machines contemplated by the present invention are shown. In FIGURE 1A, a common flotation cell is shown at 10. Flotation cell 10 includes an impeller 12 mounted centrally for rotation about a vertical axis adjacent, but spaced from the bottom of receptacle 14, and having a pulp feed trough 16 from which a feed tube 18 extends downwardly to a position just outside a stabilizer 20. Conditioning agents are received through the lower end of pipe 22. Pulp is eventually discharged through outlet 24.

Figure 1B depicts a flotation cell wherein an injection device 30 is mounted to expel a two-phase gas-liquid mixture into the cell. FIGURE 1C shows this cell mounted for operation in a bank of cells.

FIGURE 1D shows a typical flotation column 32 contemplated for use with the present invention. Flotation column 32 comprises a column 33 provided with a source of aeration 34 and wash water 35. Aeration (bubble generation) may be achieved either directly through internal spargers or after external contacting of gas with water or slurry. Wash water is usually added from an array of perforated pipes located just below the froth overflow lip. Feed 36 is introduced about one-third of the way down form the top of column 33, and descends against the rising bubbles from aeration source 34. Froth concentrate 37 overflows the top column lip, while tailings 38 exit from the bottom of the flotation column.

In accordance with the present invention, flotation machines of the type discussed above and in the prior art are provided with one or more sensors for the sensing of one or more parameters related to the processes and operation of the flotation machine. In addition, a computerized control system which may be located at the flotation machine, near the flotation machine, or at a remote location from the flotation machine is provided for interaction with the sensor or sensors in the flotation machine. This computer control system includes a control computer and one or more control devices which are actuated in response to a command signal from the control computer. Importantly, the response of the control system will preferably be based both on sensor input and on a series of expert rules,

determined initially in advance and continually updated based upon the control system's own analysis of its performance. The controller will generate and continuously update its own "process model," using the data inputs described and one or all of several advanced analysis techniques, including neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, or a combination of these. The control system will have the ability to independently select the best analysis technique for the current data set. The computer control system will actuate one or a plurality of control devices based on input from one or more monitoring sensors so as to provide real time, continuous, operational control. In addition, the control system may include a monitoring system for data logging, preventative maintenance, or failure and wear prediction. The control system may additionally include diagnostics relating to the condition of the equipment.

Referring now to FIGURE 2, a schematic is shown depicting examples of the monitoring sensors, control devices, and components and features of the control system of this invention. FIGURE 2 more particularly shows a flotation machine 40 having associated therewith one or more process sensors 42 and/or one or more equipment sensors 44, including optional video cameras (or imaging devices) 46. In addition, the flotation machine is associated with one or more operational control devices 48. The sensors 42, 44 communicate through an appropriate communications system, i.e., an analog and/or digital data acquisition interface 50 with the central control computer 52. One or more control devices 48 communicate through an appropriate communications system, i.e., an analog and/or digital control output interface 54 with the central controller 52. Alternatively, the sensors 42, 44 and the control devices 48 communicate through a single, appropriate control computer 52. As previously mentioned, the control computer 52 may be located on the flotation machine, near the flotation machine, or at a remote location such as a control room. Computer 52 has associated therewith a display 56 for displaying data and other parameters, a keyboard 58 or other means for inputting control signals, data and the like, a memory or recorder 60, and a modem 62 for inputting and outputting data to the control computer 52 from at least one remote location.

Still referring to FIGURE 2, the control computer 52 receives a variety of inputs which have been categorized generally in terms of (1) information stored in memory when

the flotation machine is manufactured; (2) information programmed at the site where the flotation machine is to be used; (3) process parameters sensed by the process sensors 42; and (4) equipment (operational) parameters sensed by the equipment sensors 44. The outputs from the control computer may be generally categorized as (1) data stored in memory 60 associated with the control computer 52; (2) operational control of the flotation machine; and (3) real time information provided to the operator at the monitor 56 associated with the control computer 52. The various inputs and outputs are summarized in the following Table.

TABLE

INPUTS

1. INFORMATION ORIGINALLY STORED IN MEMORY
   - OPERATIONS MAINTENANCE INFORMATION
   - TRAINING INFORMATION
   - PROCESS MODELS (OPTIONAL)
   - PROCESS CONTROLS, GUIDELINES (OPTIONAL)

2. INFORMATION PROGRAMMED AT SITE
   - OPERATING RANGES
   - OUTPUT PARAMETERS DESIRED
   - SITE SPECIFIC (E.G., ENVIRONMENTAL) DATA
   - PROCESS MODELS (OPTIONAL)
   - PROCESS CONTROLS, GUIDELINES (OPTIONAL)

3. PROCESS PARAMETERS SENSED
   - VOLUME AND MASS FLOWS
   - PULP LEVELS
   - FROTH LEVELS
   - FROTH MOBILITY
   - FROTH VISCOSITY
   - FROTH COLOR
   - PARTICLE SIZE DISTRIBUTION
   - SOLIDS CONCENTRATION
   - BUBBLE SIZE DISTRIBUTION
   - CHEMICAL COMPOSITION
   - BUBBLE DISTRIBUTION IN PULP
   - DENSITY
   - REGIONAL PRESSURES
   - AIR FLOW RATE
   - LIQUID FLOW RATE
   - FROTH FLOW RATE
   - REAGENT ADDITION RATES
   - VIBRATION

4. EQUIPMENT PARAMETERS SENSED
   - POSITION OF AGITATION MECHANISM
   - POSITION OF CROWDER
   - POSITION OF DISPENSER
   - ROTATIONAL SPEED OF AGITATION MECHANISM
   - ELECTRICAL POWER DRAW OF AGITATOR
   - ELECTRICAL POWER DRAW OF COMPRESSOR

OUTPUTS

1. **DATA STORED IN MEMORY**
   - **OPERATIONS DATA**
   - **PREVENTATIVE MAINTENANCE INFORMATION**
   - **FAILURE AND WEAR PREDICTION**

2. **CONTROL OF OPERATIONS**
   - **VOLUME OR MASS FLOW RATES**
   - **AIR FLOW RATES**
   - **PULP LEVELS**
   - **FROTH LEVELS**
   - **pH**
   - **PARTICLE SIZE, CONCENTRATION, DISTRIBUTION**
   - **FLOTATION REAGENT ADDITION RATE**
   - **PRESSURES**
   - **FLOW PATTERNS**
   - **AGITATION SPEED**
   - **POSITION / ORIENTATION OF AGITATOR**
   - **POSITION / ORIENTATION OF DISPERSER**
   - **POSITION / ORIENTATION OF DRAFT TUBE**
   - **POWER DRAW**

3. **READ OUT AT MONITOR**
   - **DIAGNOSTICS OF CONDITION OF EQUIPMENT**
   - **ORDER SPARE PARTS**
   - **MODEM/FAX FOR SPARE PARTS**
   - **READOUT OF OPERATING PARAMETERS**
   - **SCADA OR DCS**

Information Stored in Memory

Examples of information originally stored in memory include information relating to the operation and maintenance of the flotation machine and operator training information, all of which will be readily available to an operator on display screen 56 associated with control computer 52.

Information Programmed at Site

Examples of information programmed at the site where the flotation machine is to be used include the operating ranges, equipment parameters, and desired feed parameters, along with other site-specific data and environmental factors. Input into the control computer also includes various process models, process controls, and guidelines. These models and goals may be either stored in memory or programmed at the site as appropriate.

Process and Equipment Parameters

A further important feature of the present invention is the large number of process and equipment sensors 42, 44 which sense a variety of aspects relating to the flotation machine, its operations, and its feed, tailings, and float streams. Particularly important are sensors relating to rate of chemical addition, power consumption, aeration rate, and froth layer thickness. Other process parameters which may be sensed include, but are not limited to the bubble loading; volume or mass flow rates into the feed, concentrate, froth, or tailings streams; the air flow rates into the feed, concentrate, froth, or tailings streams; the density of the feed, concentrate, froth, or tailings streams; the chemical or mineralogical composition of the feed, concentrate, froth, or tailings streams; the pulp or froth levels; the particle size, concentration, and distribution of solids in the feed, concentrate, froth, or tailings streams; the bubble size, color, and distribution in the feed, concentrate, froth, or tailings streams; the pH of the feed, concentrate, froth, or tailings streams; the rate of addition of flotation reagents, including frothing agents, collecting agents, promoting agents, depressing agents, and the like; the regional pressures and flow patterns within the flotation machine; acoustic emissions from the flotation machine; or digitized video images of the froth surface or other key parts of the process, analyzed to determine the key characteristics of the subject being imaged.

Equipment parameters which may be sensed include but are not limited to agitation speed, induced or forced air flow rate, position and orientation of a froth crowding device, position and orientation of a draft tube, position and orientation of an agitator, position and orientation of a disperser, power draw of agitator motor; and power draw of other devices such as a compressor.

It will be appreciated that it is often difficult to sense and communicate certain parameters in real time within flotation machines. Thus, a variety of technologies including ultrasonic absorption and reflection, laser-heated cavity spectroscopy, laser-induced breakdown spectroscopy (LIBS), laser-induced mass spectroscopy (LIMS), X-ray fluorescence spectroscopy, neutron activation spectroscopy, pressure measurement, microwave or millimeter wave radar reflectance or absorption, and other optical and acoustic methods may be utilized in the present invention. A suitable microwave sensor for sensing moisture and other constituents in the solid and liquid phase influent and effluent streams is described in U.S. Patent No. 5,455,516, all of the contents of which are incorporated herein by reference. An example of a suitable apparatus for sensing using LIBS is disclosed in U.S. Patent No. 5,379,103, all of the contents of which are incorporated herein by reference. An example of a suitable apparatus for sensing LIMS is the LASMA Laser Mass Analyzer available from Advanced Power Technologies, Inc. of Washington, D.C. A preferred embodiment employing a laser spectroscopy-based sensor is described in detail hereinafter with reference to FIGURES 3-6.

In a suitable acoustic sensor, one or more microphones, single-axis accelerometers or multi-axis accelerometers are positioned on or near the flotation machine. Acoustic emissions emanating from the machine, including sub-sonic, sonic, and ultrasonic waves, are detected either directly by accelerometers, or by microphones as they are transmitted through the air. Acoustic emissions are converted to electromagnetic signals and digitized for processing. Processing may include, but is not limited to, Fourier transformation, fast Fourier transformation and wavelet transformation. The signal is known to characterize changes in the process taking place in the flotation machine. However, a stochastic model relating the acoustic emission signal to the process and the machine's performance is typically too complex to be useful. Therefore, the transformed emissions signal is preferably

used as an input to an advanced control system, as described hereinafter where it may be used in a neural network or other heuristic modeling system to control the performance of the machine and the flotation process.

Suitable techniques for communication among the sensors, control computer, and other components include hard-wired electrical systems, optical systems, RF systems, acoustic systems, video systems, and ultrasonic systems.

Data Stored in Memory

Referring more particularly to the data stored in memory, it will be appreciated that the computerized monitoring and control system of this invention may utilize the aforementioned sensors to monitor various parameters with respect to time and thereby provide a detailed historical record of the flotation machine operation 66. This record may be used by the control computer to model flotation machine operation, adjust models for flotation machine operation, or generally learn how the flotation machine behaves in response to changes in various inputs. At any time, such operating data may be retrieved from the memory of a computer local to the flotation machine or remotely. The data may be displayed in real time while the flotation machine is operating using monitor 56, or as a historical record of some prior operating sequence. This record may also be used to provide a data log, provide trending and preventative maintenance information, predict failure, and predict machine wear 68. Pre-formatted reports may present the retrieved data to show information such as operating hours, alarms generated, number of starts, number of trips, electrical power used, maximum and minimum values for measured variables, total feed processed, and the like. Using the operating data, the flotation equipment manufacturer may recommend measures to avoid down time and to optimize run time. Also, maintenance procedures may be suggested based on the operating log of elapsed run time and unusual operating conditions. The operating data log thus helps to trouble shoot various operating conditions of the flotation equipment. This enhances the flotation equipment manufacturer's ability to solve the customer's operational problems and to keep equipment on line. Optionally, these data 66,68 may then be used to provide alarms or emergency notification 70 when certain critical levels are reached.

Control of Operations

Controller 52 preferably communicates through standard communication cards used with personal computers or workstations. As such, Ethernet, RS-232, and modem capabilities exist for the operator's use. The present invention therefore allows a given plant to collect flotation machine operating data through a plant-wide Ethernet or other network. Additionally, the present invention may communicate with other process devices not supplied by the manufacturer. In this way the operator uses the control and monitoring system of this invention to gather information on a larger portion of the process.

Using a connected plant network, the operator may monitor the flotation machine's real time performance and historical log. Suitable software for this activity includes operator screens for data display, and message displays for operating assistance, and may also include an on-line operation and maintenance manual. The operator may also control and optimize the performance of the flotation machine through the plant network. The operating parameters as described below may also become part of an overall Supervisory Control and Data Acquisition (SCADA) system or Distributed Control System (DCS). As is well known, in a SCADA system or DCS, microprocessor devices convert plant measurement and status inputs into computer data for logging and transmission to higher level processors. The SCADA system or DCS therefore connects to many controllers and field devices to gather information and make global decisions. Supervisory, expert controllers make strategic decisions for the operation of a process unit or plant and send out set points to dedicated controllers which will make the changes to actuators and ultimately the process as a whole.

Continuing to refer to FIGURE 2, a further important feature of this invention is that in response to the one or more parameters sensed by the sensors 42, 44, the operation of the flotation machine and thereby its ultimate efficiency can be adjusted, changed, and preferably optimized using one or more advanced computerized control methods. Control of the machine includes control of mechanical state and operation, and control of operating ranges to optimize safe as well as efficient operation. Such advanced, computerized control methods include but are not limited to neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, or a combination thereof.

Thus, in a preferred embodiment, this invention comprises at least one of these control methods and other methods more advanced than conventional, stabilizing control methods, for example, the simple feedback or feed forward control loops of the prior art. The response of the system is based on a series of expert rules, determined initially in advance and continually updated based upon the control system's own analysis of its performance. The control system will generate and continuously update its own "process model" using the sensor inputs described and the above-mentioned analysis techniques. The control system may have the ability to independently select the best analysis technique for the current data set.

While controller 52 may operate using any one or more of a plurality of advanced computerized control methods, it is also contemplated that these methods may be combined with one or more of the prior art methods, including feed forward or feedback control loops. Feed forward is where process and machine measurements (or calculated, inferred, modeled variables normally considered ahead of the machine in the process) are used in the controller 52 to effectively control the operation of the flotation machine. Feed forward schemes inherently acknowledge that the conditions and state of the feed material to the flotation machine change over time and that by sensing or calculating these changes before they enter the flotation machine, control schemes can be more effective than otherwise might be possible. Feedback is where measurements and calculated values that indicate process performance and machine state are used by controller 52 and the control scheme contained therein to stabilize the performance and to optimize performance as feed conditions changes and machine performance changes in reference to set points and optimization objectives.

Process and machine models are embedded in controller 52, as are methods to evaluate the models to determine the present and future optimum operating conditions for the machine. Optimum conditions are specified by flexible, objective functions that are entered into the controller 52 by the operators or plant control system that is dealing with plant-wide control and optimization. The models contained therein are adaptive in that their form or mathematical representation, as well as the parameters associated with any given model, can change as required. These models include, but are not limited to first principles and phenomenological models, as well as all classes of empirical models that include neural

network representations and other state space approaches. Optimization is accomplished by combining the contained knowledge of the process and machine through these models with expert system rules about the same. These rules embody operational facts and heuristic knowledge about the flotation machine and the process streams being processed. The rule system can embody both crisp and fuzzy representations and combine all feed forward, feedback, and model representations of the machine and process to maintain stable, safe, and also optimal operation, including the machine and the process. Determination of the optimum operating states includes evaluating the model representation of the machine and process. This is done by combination of the expert system rules and models in conjunction with the objective functions. Genetic algorithms and other optimization methods are used to evaluate the models to determine the best possible operating conditions at any point in time. These methods are combined in such a way that the combined control approach changes and learns over time and adapts to improve performance with regard to the machine and the process performance.

A detailed description of a suitable system employing an internal process model as described herein for use in connection with the present invention is disclosed in U.S. Application Serial No. 60/037,355, filed February 21, 1997, assigned to the assignee hereof, all of the contents which are incorporated herein by reference.

As discussed above, the adaptive control system of this invention uses one or a combination of internal and/or external machine and/or process variables to characterize or control the performance of the flotation machine, in terms of the desired process outputs. Preferably, the control system continually updates its knowledge of the process, so that its control performance improves over time.

One of the important calculated values included in this process is the economic performance of the flotation machine. Economic performance includes base machine operating costs, including power usage and chemical additive usage, the normalized performance cost dealing with throughput rates and the quality of the products produced, both in absolute terms and terms normalized for feed conditions, and the economic value of the products produced.

Still referring to FIGURE 2, in response to the one or more parameters sensed by the sensors 42 and 44, the advanced control system of the microprocessor may actuate one or more process and/or equipment control devices 48 to control operations. The operational outputs from the central controller 52 may be processed though a control output interface 54. In some cases, the control devices will be actuated if certain sensed parameters are outside the normal or preselected flotation machine operating range. This operating range may be programmed into the control system either prior to or during operation. Examples of operational parameters which may be adjusted include but are not limited to volume or mass flow rates into the feed, concentrate, froth, or tailings streams; the induced or forced air flow rates into the feed, concentrate, froth, or tailings streams; the pulp or froth levels; the particle size, concentration, and distribution of solids in the feed, concentrate, froth, or tailings streams; the bubble size, bubble volume and bubble distribution in the feed, concentrate, froth, or tailings streams; the pH of the feed, concentrate, froth, or tailings streams; the rate of addition of flotation reagents, including frothing agents, collecting agents, promoting agents, depressing agents and the like; the regional pressures and flow patterns within the flotation machine; the agitation speed in the machine; the position and orientation of a froth crowding device; the position and orientation of a draft tube; the position and orientation of an agitator; the position and orientation of a disperser; the power draw of agitator motor; and the power draw of other devices, such a compressor. The foregoing operational controls and examples of actual control devices which will provide such operational control will be described in more detail below.

Readout at Monitor

Referring still to FIGURE 2, other outputs include the real time status of various parameters at the flotation machine. Thus, the operator may use the computerized control and monitoring system of the present invention to diagnose the present condition of the equipment, order spare parts (a modem/fax 66 may be included for spare parts ordering), or obtain a read-out as part of a SCADA system or DCS as described above.

A particularly preferred embodiment of the present invention employs an imaging system comprising video cameras or the like 46 producing images which are converted to

data usable by the process models of the present invention. Flotation plant operators currently use visual observation of the color and consistency of flotation froths to estimate the performance of a circuit. Automation of the visual analysis of froth compositions would provide greatly enhanced process control. A description of a video sensor system for use in mineral processing operations is described in by J.M. Oestreich, et al., Minerals Engineering, Vol. 8, Nos.1-2, pp. 31-39, 1995, incorporated herein by reference. The color sensor system described therein comprises a color video camera, a light source, a video-capture board, a computer, and a computer program that compares measured color vector angles to a previously stored calibration curve. Several cameras may be connected to a single color sensor computer or a single camera may simultaneously observe several locations using a network of fiber-optic cables.

This preferred embodiment of the present invention may further comprise an advanced control system employing both pattern analysis by neural networks, as well as statistics and color vector analysis. As described by Oestreich, et al., above, gray level dependence matrix methods are used to extract statistical features form digitized images of froths. These statistical features constitute a compact set of the essential data contained in the original image, which can then be related to the metallurgical parameters of the flotation process by means of neural nets. Either supervised neural nets, such as learning vector quantization systems, unsupervised nets, such as self-organized mappings, or a self-organizing neural net which can map high-dimensional input vectors to lower-dimensional maps in a topological, order-preserving manner are used. Topological maps have the advantage that they can be used to track the performance of flotation processes on a continuous basis, as opposed to the discrete classification by other classification paradigms. For example, when considering a process system consisting of a bank of flotation cells, the process could be monitored by means of a characteristic profile on a two-dimensional feature map, which would enable the early detection of deviation from optimal conditions by intelligent automation systems through comparison of the actual profile of the system with an ideal or optimal profile.

In addition to color, both viscosity and mobility of froths may be recorded and analyzed by visual means. Thus, in a further embodiment of this invention, a series of

modules are used to monitor different features with a high degree of accuracy. Thus a machine vision system based on the interpretation of visual features of froth structure has a modular structure, in which one module will distinguish between froths based on differences in morphology, a next module will base the distinction on froth mobility, another will extract chromatic information, another average bubble size, and so on.

Referring now to FIGURE 3, a preferred embodiment of the present invention is shown wherein the intelligent control system shown generally at 110 includes one or more laser-induced breakdown spectroscopy sensors (LIBS sensors) and/or laser-induced mass spectroscopy sensors (LIMS sensors). LIBS and LIMS sensors are particularly useful in the determination of elemental composition *in situ*, that is, without the need for removal of a sample for analysis at a separate location. This represents a significant advance over the prior art, for example analysis of composition by X-ray analyzers. X-ray analyzers have in fact been used to determine concentration of certain elements in flotation flow streams, but require removal of a sample and analysis at a separate location. Each analysis generally requires at least fifteen to twenty minutes. Furthermore, such analyses must necessarily be discrete measurements, and thus cannot provide on-going (that is, continual), real-time, composition determinations.

In contrast, the control system 110 according to the present invention allows fast, discrete or continuous, real-time analysis. The general configuration of the intelligent control system according to the present invention 110 comprises the control computer 112 described in detail above, receiving data from an LIBS sensor 114. An LIBS-type sensor suitable for use with the present invention is described in aforementioned U.S. Patent No. 5,379,103 to Zigler. Such sensors are capable of measuring the percent concentration of one or more elements in a mixture. Controller 112 actuates at least one control device 116 in response to the data received from the LIBS sensor 114 and an internal process model as described in detail above. Control device 116 affects an operational parameter of the processing system 118 containing a multi-component mixture 120.

LIBS sensors are particularly suited for determining elemental composition in essentially dry or dewatered solids or froths. Thus, while the particular embodiments described herein are directed to a froth flotation machine, other processing systems using

LIBS sensors in association with a controller to monitor composition are within the scope of the present invention. Such processing systems are those which have sample streams which do not need to be dry or dewatered, including, but not limited to, thickeners, filters, centrifuges, analysis of the molten metal or slag streams of smelting furnaces, chemical process solutions, and the like.

A particularly preferred embodiment using LIBS sensors in conjunction with the intelligent control system according to the present invention is shown generally at 210 in FIGURE 4. This embodiment exemplifies analysis and control of samples which do not require dewatering. Crushed ore 212 for separation by at least one froth flotation machine 214 is moved along belt 216 to the grinding apparatus 218. After grinding , the ore is conditioned or stored in conditioning tank or feed box 222. Reagents may be added to the grinding apparatus 218 and/or to the conditioning tank/feed box 222 via reagent addition system 224. The ground, conditioned material is then subjected to froth flotation in at least one flotation machine 214. LIBS sensor 226 analyzes the composition of one or more constituents of the crushed ore 212, and communicates these data to the intelligent controller 228. Preferably, the controller uses these data as input to a computer program which uses neural network and pattern analysis to characterize the sample and estimate its composition in terms of chemical compounds or minerals contained. In response to this analysis and an internal process model, the controller may then send signals to the grinding apparatus 218, to the reagent addition system 224 to make adjustments to the rate of reagent addition, or it may actuate at least one control device 230 affecting the operational parameters of the froth flotation machine. Such operational parameters include, but are not limited to, the impeller speed, the aeration rate, the froth wash, flow rate, the various levels of each phase, the feed rate, and the like.

Referring to FIGURE 5, a second preferred embodiment using LIBS sensors in conjunction with the intelligent control system of the present invention is shown generally at 231. In this embodiment, the LIBS sensor performs an analysis of a few key elements in dry or dewatered samples, for example the concentration of copper, molybdenum, iron, silica, and magnesium in copper flotation concentrates. Thus, LIBS sensor 232 is positioned close to the froth overflow 234 of froth flotation machine 218. The LIBS sensor therefore

incorporates ruggedized optics to allow operation on or near process streams, providing tolerance for vibration, dust, and moisture. The sensor 232 may also comprise one more mechanisms for movement of the device, by translation, rotation, or random dithering, so that successive analyses are taken from different parts of the sample stream. Data from sensor 232 are communicated to control computer 228, which may actuate one or more control devices as described above.

The above-described embodiments are directed to analysis of essentially dry or dewatered samples. Such embodiments are particularly useful in that the analysis is fast, and provides real-time data with respect to a process flow. In a third preferred embodiment of the present invention using LIBS sensors, wet samples are dewatered and analyzed to provide data for the intelligent control system. This embodiment still provides fast, real-time analysis. Referring to FIGURE 6A-B, LIBS sensor 312 senses a sample stream 314 from conditioner tank/feed box 316. LIBS sensor 318 senses a sample stream 320 from tailings 322 from froth flotation machine 324. Data from each sensor are communicated to the control computer 326, which in turn affects the operational parameters of the froth flotation system by actuating various control devices as described above. Because the sample streams 320, 322 contain moisture, each must be dewatered prior to analysis by the LIBS sensor. Accordingly, each sample stream is first passed through the system 340 as shown in FIGURE 6B.

The system 340 comprises the sample feed 320, 322 (usually in the form of a slurry), a slurry head tank 342, and a continuous, vacuum belt-press filter 344. Preferred vacuum belt-press filters are available from Eimco, Salt Lake City, Utah. Both slurry head tank 342 and vacuum belt-press filter 344 must be appropriately sized to provide the required level of dewatering prior to activation for analysis. Slurry 320, 322 enters the head tank 342, and is discharged evenly onto the filter belt 346, where it is dewatered prior to analysis and then discharged. LIBS sensors 321, 318 analyze the dewatered sample 348. This system is particularly advantageous in that it allows analysis of materials of unknown moisture content, without requiring that samples be completely dried. The materials may be analyzed without the necessity of transport to a remote site.

In still another preferred embodiment, other dewatering devices may also be used as appropriate. For example, the device 350 shown in FIG. 6C functions by passing a sampling medium 352, for example, a moving belt or a rotating disk, through the slurry 354 being analyzed, to capture by adhesion a thin layer 356 of the solids in the slurry. Said thin layer 356 may then be dried by a moving airstream 358, prior to LIBS analysis, and removed from the sampling medium 352 by a water spray or a scraper 360 after analysis.

While the present invention has been described in conjunction with froth flotation machines, it will be appreciated that many of the sensing, monitoring and control techniques and instrumentation may be used in connection with any processing system for a multicomponent mixture.

While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustrations and not limitation.

What is claimed is:

CLAIM 1. A froth flotation machine, the flotation machine comprising:

at least one laser spectroscopy sensor for continual sensing in real time at least one parameter related to composition of at least one of the input and output flows associated with the flotation machine;

a control computer associated with the flotation machine and communicating with said sensor; and

a control device for controlling said flotation machine, said control device communicating with said control computer, wherein said control computer actuates said control device in response to input from the sensor.

CLAIM 2. The froth flotation machine according to claim 1, wherein said flotation machine is selected from the group consisting of flotation cells and flotation columns.

CLAIM 3. The froth flotation machine according to claim 1, including one or more additional sensors selected from the group consisting of sensors to sense input volume of pulp, input mass of pulp, input density of pulp, pulp level, froth level, froth mass, froth mobility, froth viscosity, froth color, tailings output volume, tailings output density, tailings output mass, particle size, particle distribution, particle concentration, bubble size, bubble distribution, bubble concentration, chemical or mineralogical composition, regional pressures, air flow rate liquid flow rate, froth flow rate, reagent addition rate, bubble loading and acoustic emissions.

CLAIM 4. The froth flotation machine according to claim 1, wherein said laser spectroscopy sensor is selected from the group consisting of laser-induced breakdown spectroscopy and laser induced mass spectroscopy sensors.

CLAIM 5. The froth flotation machine according to claim 1, wherein said control computer includes a process model which is at least partially self-generated and continually updated and adapted.

CLAIM 6. The froth flotation machine according to claim 5 wherein:

said process model is continually updated using at least one of the advanced analysis techniques selected from the group consisting of neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition and categorical analysis.

CLAIM 7. The froth flotation machine according to claim 1, including at least one additional sensor, wherein said additional sensor comprises at least one video camera.

CLAIM 8. The froth flotation machine of claim 1 wherein:

said at least one laser spectroscopy sensor is positioned to analyze a sample of the material to be separated prior to such material being added to the input flow.

CLAIM 9. The froth flotation machine of claim 1 wherein:

said at least one laser spectroscopy sensor is positioned to analyze a sample of the material to be separated subsequent to drying or dewatering.

CLAIM 10. The froth machine of claim 1 wherein said at least one laser spectroscopy sensor includes:

at least one mechanism for moving said sensor by at least one of translation, rotation or dithering.

CLAIM 11. The froth machine of claim 1 including:

at least one drying device associated with said flotation machine for drying a sample of the material to be separated prior to analysis by said at least one laser spectroscopy sensor.

CLAIM 12. The froth flotation machine according to claim 1, wherein said control device controls at least one operational parameter selected from the group consisting of agitation mechanism position, crowder shape, crowder position, disperser position, draft tube

position, agitation speed, electrical power draw, reagent addition rate, aeration, froth wash, froth level, pulp level, feed rate, bubble size, bubble volume and bubble distribution.

CLAIM 13. A method for controlling a processing system for a multi-component mixture, the method comprising:

continual sensing in real time at least one parameter related to composition of at least one of input and output flows associated with the system using at least one laser spectroscopy sensor; and

controlling the processing system based, at least in part, on information from said sensor system.

CLAIM 14. The method according to claim 13 further comprising:

analyzing said at least one parameter by means of an internal process model which is at least partially self-generated and continually updated and adapted.

CLAIM 15. The method according to claim 14 wherein said internal process model is continually updated by means of an advanced control technique selected from the group consisting of neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, or a combination thereof.

CLAIM 16. The method according to claim 15 wherein said internal process model is further generated and updated by means of at least one technique selected from the group consisting of feed forward and feedback loops.

CLAIM 17. The method according to claim 13 including one more additional sensors selected from the group consisting of sensors to sense input volume of pulp, input mass of pulp, input density of pulp, pulp level, froth level, froth mass, froth mobility, froth viscosity, froth color, tailings output volume, tailings output density, tailings output mass, particle size, particle distribution, particle concentration, bubble size, bubble distribution, bubble

concentration, chemical composition, reagent addition, regional pressures, air flow rate, liquid flow rate, froth flow rate, reagent addition rate, bubble loading and acoustic emissions.

CLAIM 18. The method according to claim 13, wherein said laser spectroscopy sensor is selected from the group consisting of laser-induced breakdown spectroscopy and laser induced mass spectroscopy sensors.

CLAIM 19. The method according to claim 13, wherein:

said controlling includes control of at least one operational parameter selected from the group consisting of agitation mechanism position, crowder shape, crowder position, disperser position, draft tube position, agitation speed, electrical power draw, reagent addition rate, aeration, froth wash, froth level, pulp level, feed rate, bubble size, bubble volume and bubble distribution.

CLAIM 20. In a froth flotation machine having at least one associated sensor, the improvement comprising:

a control system for analyzing sensor inputs in terms of at least one self-generated, continuously updated, internal model, based at least partially on advanced analysis techniques selected from the group consisting of neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, or a combination thereof.

CLAIM 21. The froth flotation machine of claim 20 wherein:

said control system is at least partially embedded in said froth flotation machine.

CLAIM 22. The froth flotation machine of claim 20 including a sensor which comprises one or more acoustic sensors for detecting acoustic emissions emanating from said froth flotation machine and wherein said control system processes signals received from said sensor to characterize changes in the process taking place in the froth flotation machine.

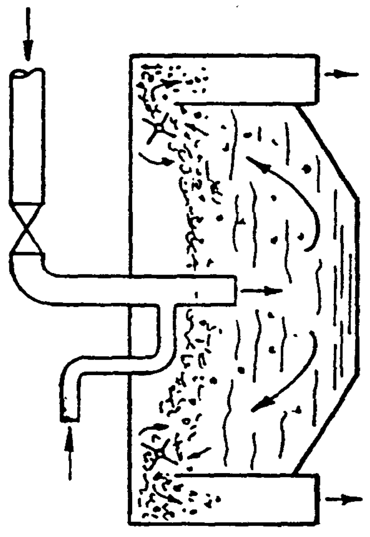


FIG. 1B (PRIOR ART)

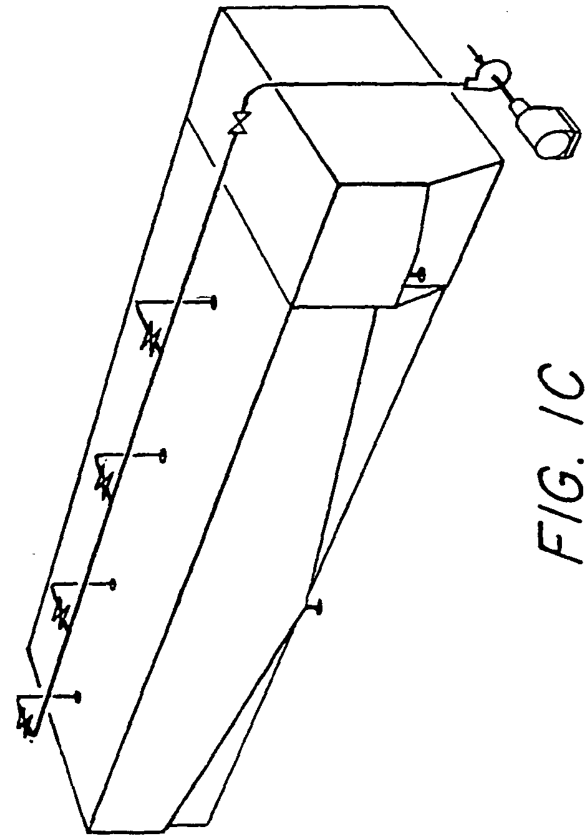


FIG. 1C (PRIOR ART)

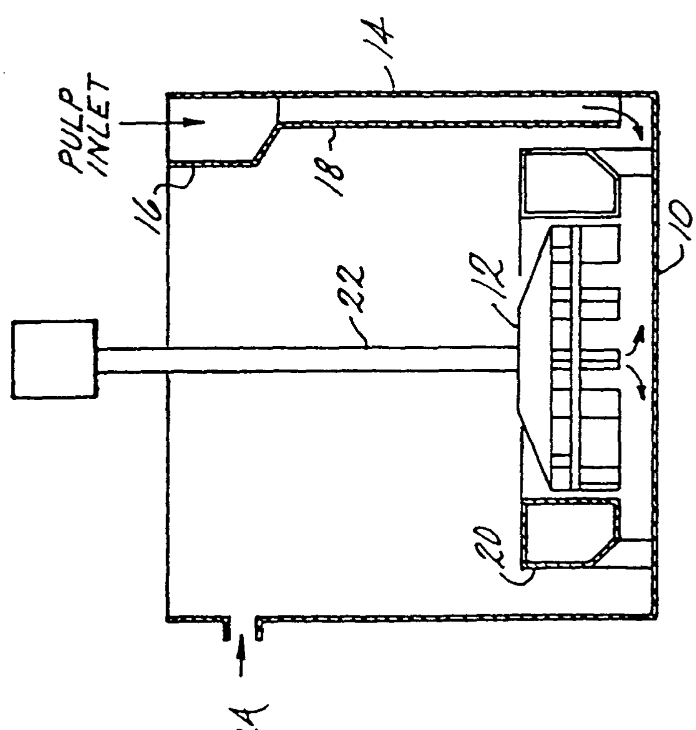


FIG. 1A (PRIOR ART)

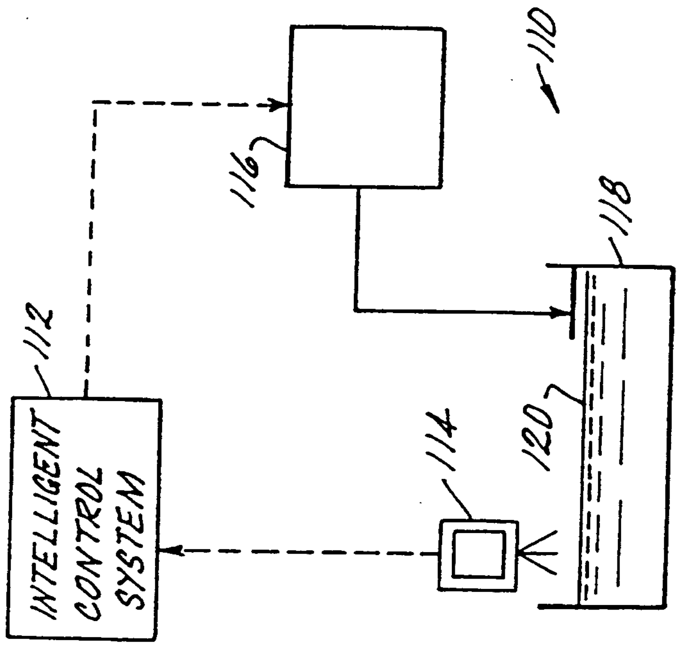


FIG. 3

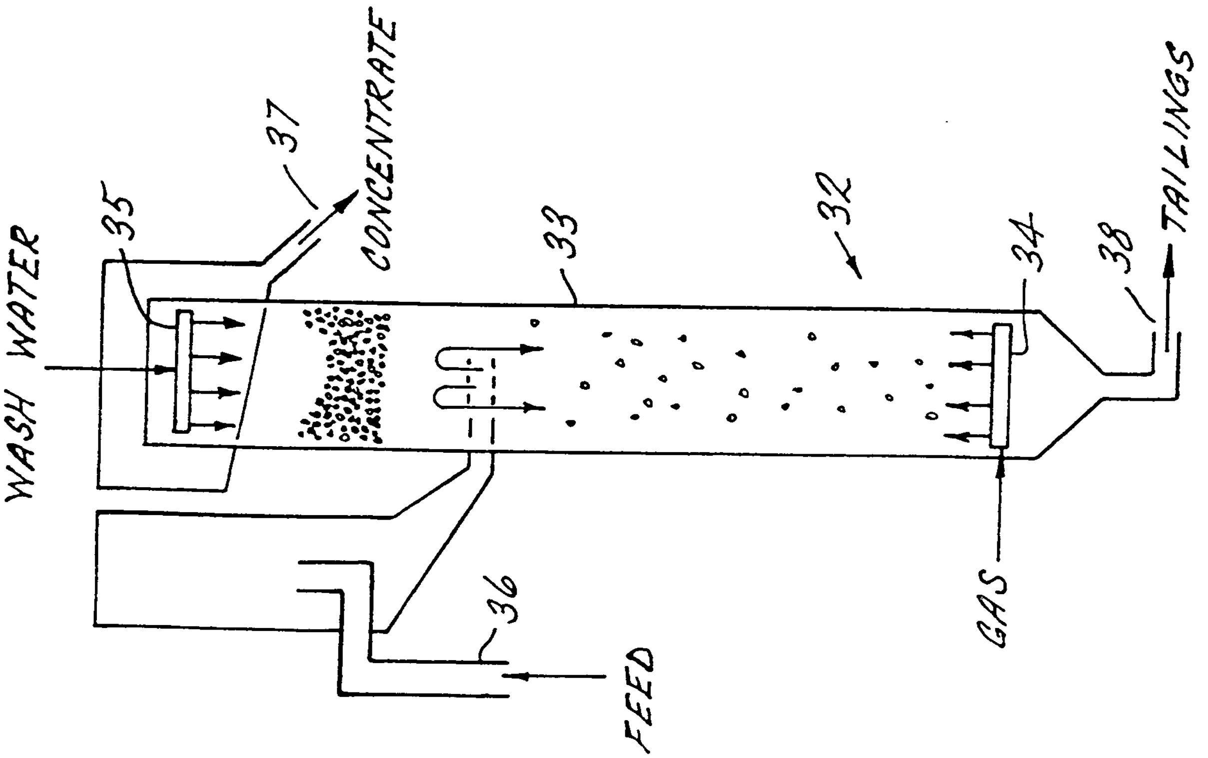
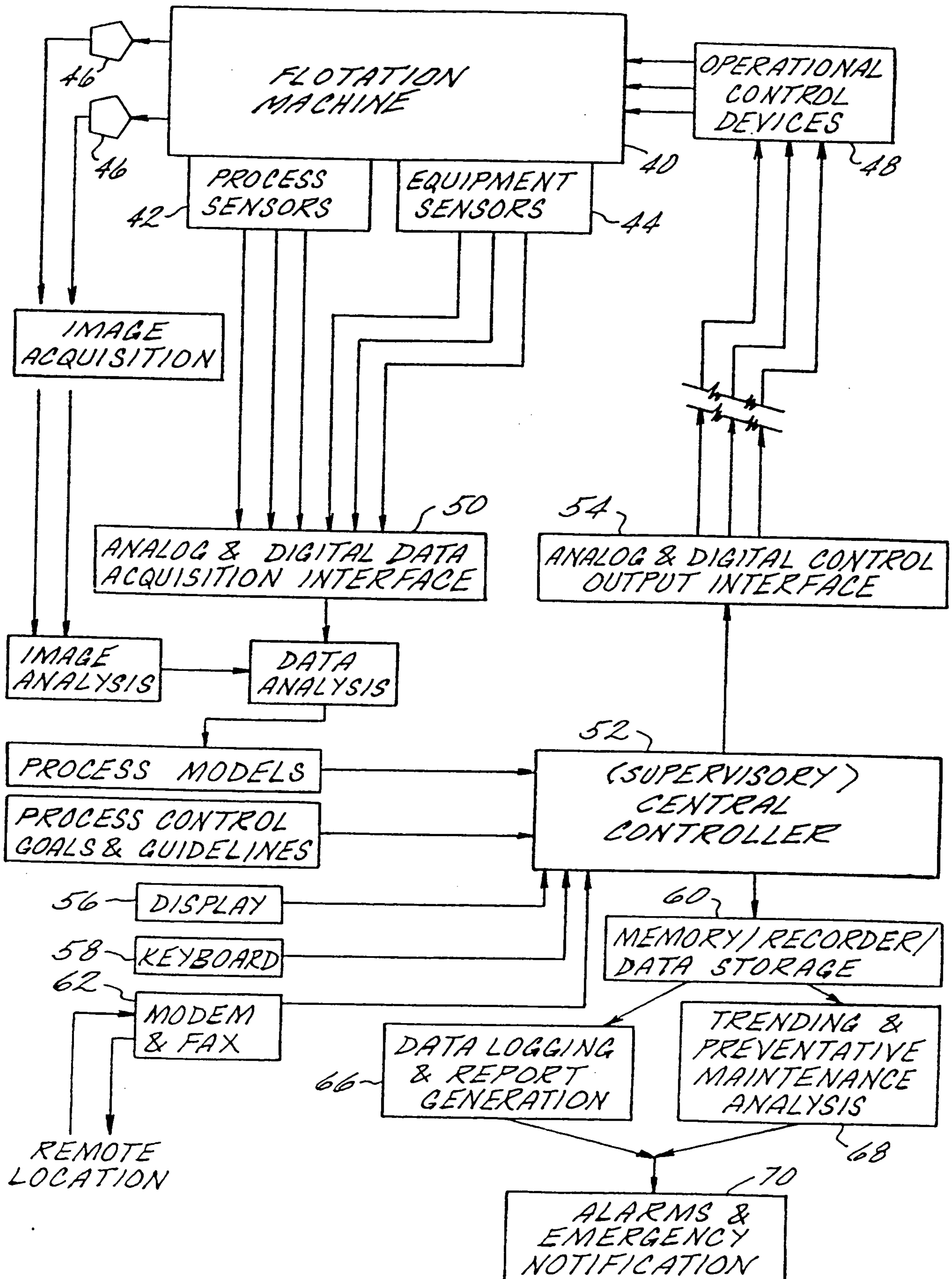


FIG. 1D (PRIOR ART)



FLOTATION MACHINE
46
46
40
PROCESS SENSORS
42
EQUIPMENT SENSORS
44
OPERATIONAL CONTROL DEVICES
48
IMAGE ACQUISITION
50
ANALOG & DIGITAL DATA ACQUISITION INTERFACE
54
ANALOG & DIGITAL CONTROL OUTPUT INTERFACE
IMAGE ANALYSIS
DATA ANALYSIS
52
PROCESS MODELS
PROCESS CONTROL GOALS & GUIDELINES
(SUPERVISORY) CENTRAL CONTROLLER
56
DISPLAY
58
KEYBOARD
62
MODEM & FAX
60
MEMORY/RECORDER/ DATA STORAGE
DATA LOGGING & REPORT GENERATION
66
TRENDING & PREVENTATIVE MAINTENANCE ANALYSIS
68
REMOTE LOCATION
70
ALARMS & EMERGENCY NOTIFICATION

FIG. 2

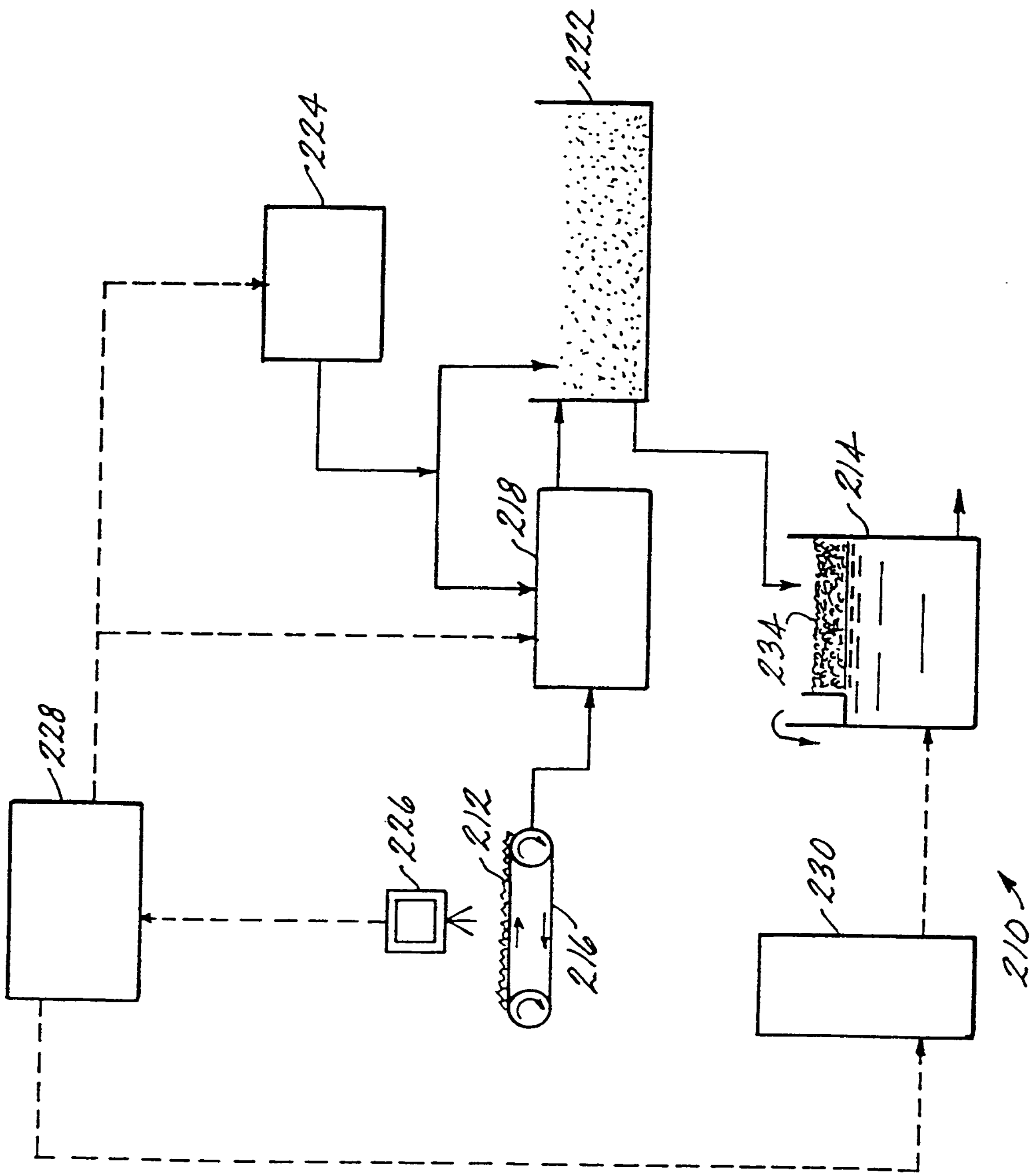


FIG. 4

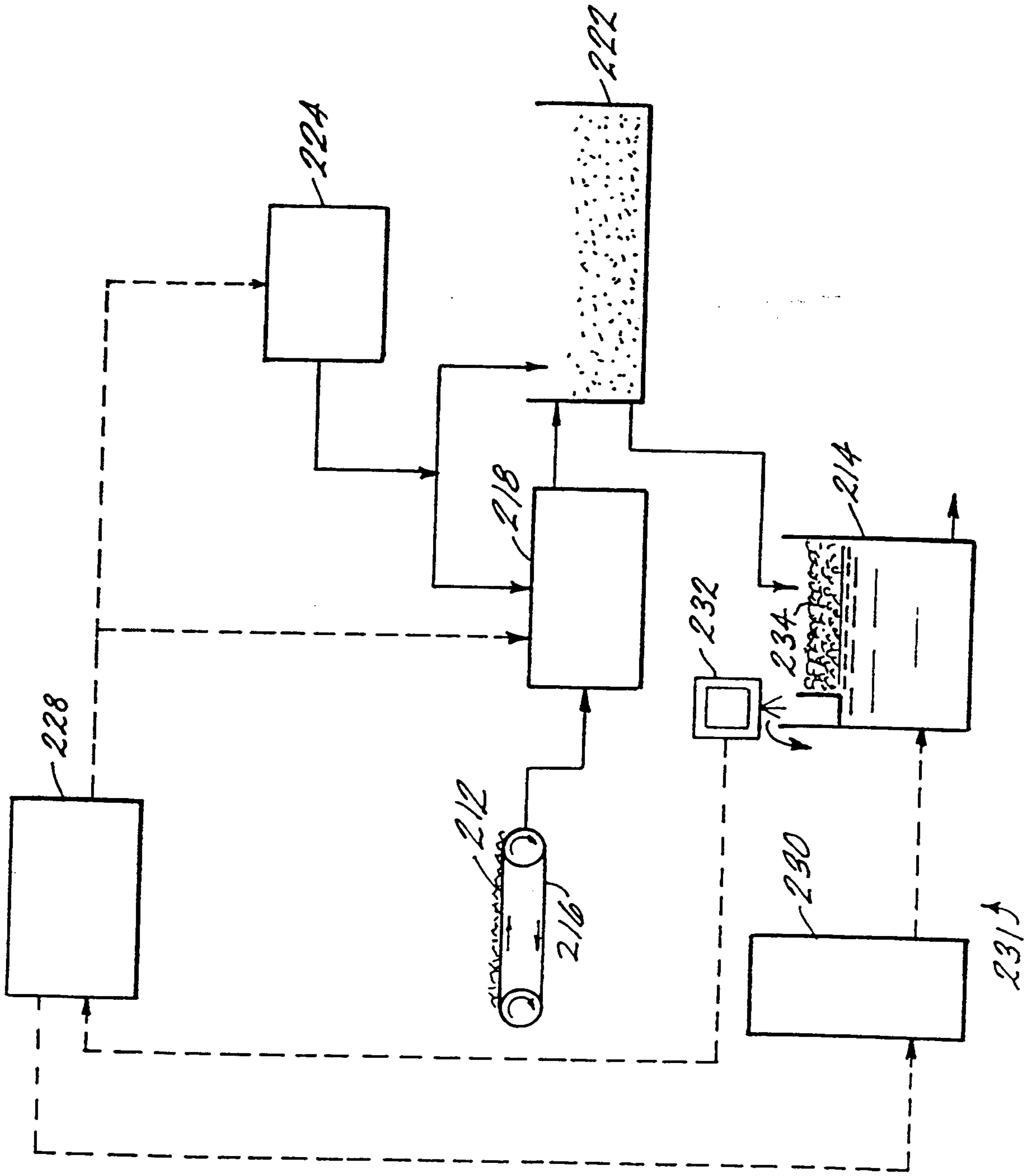


FIG. 5

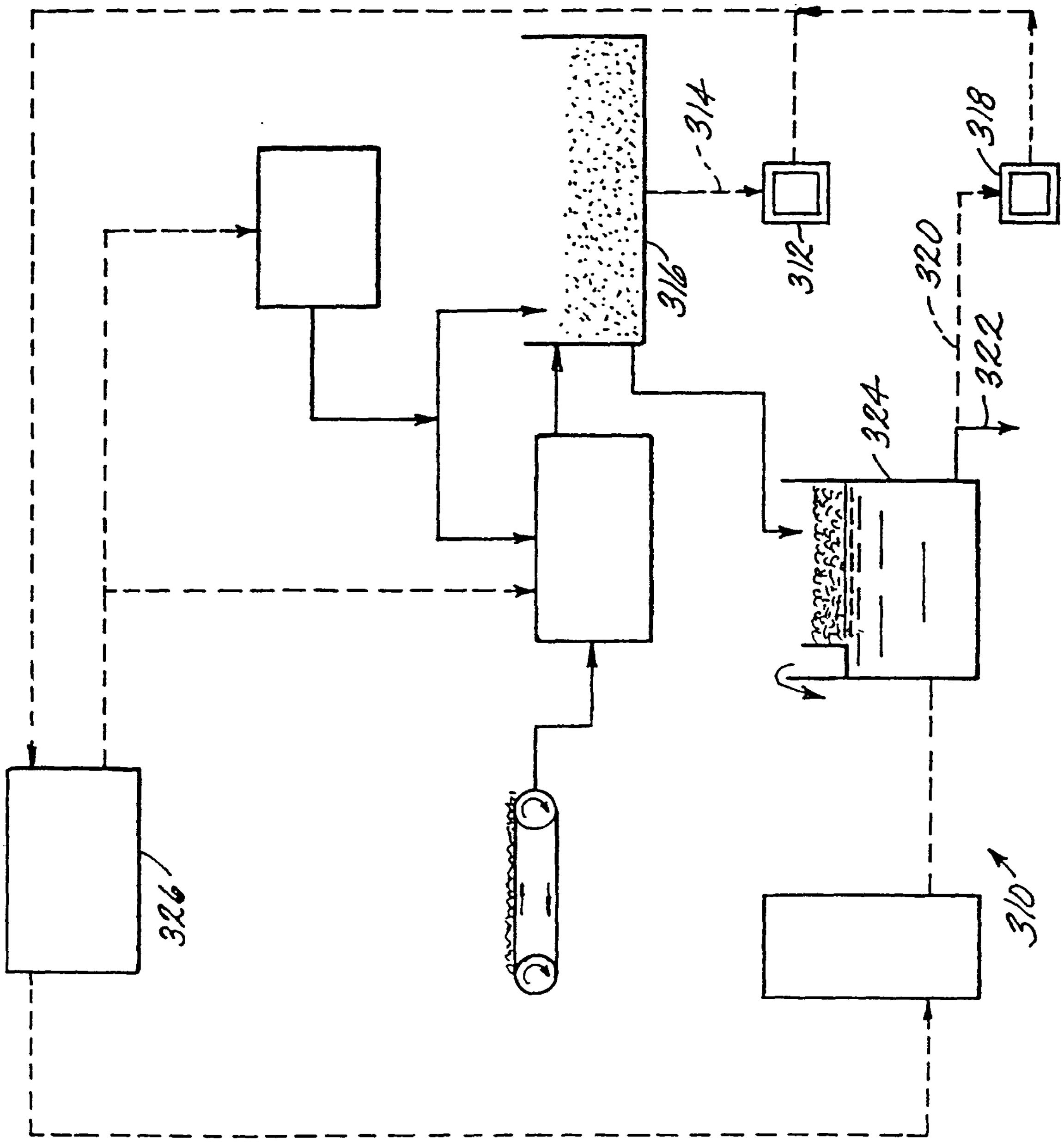


FIG. 6A

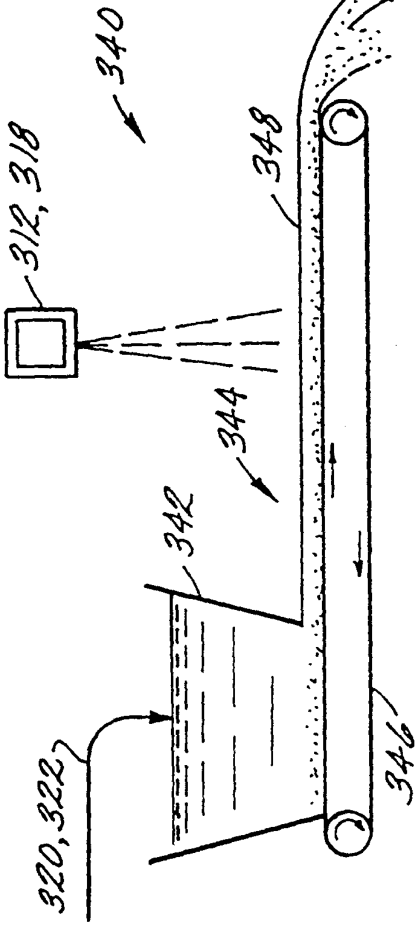

340
312, 318
348
344
342
346
320, 322

FIG. 6B

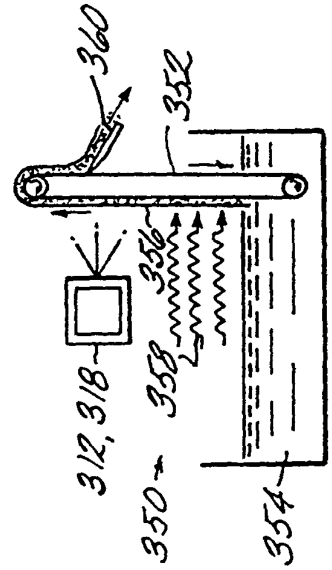

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FIG. 6C

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON INDUSTRIAL ELECTRONIC CONTROL AND INSTRUMENTATION (IECON), vol. 2/3, 5 - 9 September 1994, BOLOGNA, pages 1375-1380, XP000525528 CIPRIANO ET AL: "Fuzzy Model Based Control for a Mineral Flotation Plant" see abstract see introduction	20
Y		5,6, 14-16,22
A		1,2,12, 13,19
X	US 5 480 562 A (LEMELSON) 2 January 1996 see abstract see column 2, line 4 - column 3, line 43; figures 1,2	13-19
A		1,3-8, 10,12,20
A	US 5 491 344 A (KENNY ET AL) 13 February 1996 see abstract see column 3, line 65 - column 4, line 10 see column 5, line 3 - column 7, line 63 see column 10, line 8 - line 50; figures 1-7	1,4, 8-10,13, 18
A	US 3 551 897 A (COOPER) 29 December 1970 cited in the application see column 3, line 14 - column 4, line 52; figure	1-3,5, 12-14, 16,17, 19,20
A	US 4 797 550 A (NELSON ET AL) 10 January 1989 cited in the application see abstract see column 2, line 52 - column 3, line 19; figure 1	1,2,10, 12,13, 16,19,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/08871

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 3319922 A	06-12-84	NONE	
US 5011595 A	30-04-91	NONE	
US 5480562 A	02-01-96	NONE	
US 5491344 A	13-02-96	NONE	
US 3551897 A	29-12-70	NONE	
US 4797550 A	10-01-89	AU 2339388 A	11-05-89
		CA 1292296 A	19-11-91
		CN 1033016 A,B	24-05-89
		DE 3837557 A	18-05-89
		GB 2212263 A,B	19-07-89